Sociobiology
An international journal on social insects

Research article - Termites

Utility of Acoustical Detection of *Coptotermes formosanus* (Isoptera: Rhinotermitidae)

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Article History
Edited by:
Evandro N. Silva, UEFS - Brazil
Received 29 November 2012
Initial acceptance 02 January 2013
Final acceptance 14 February 2013

Keywords
AED 2000, AED 2010, Formosan subterranean termite, tree, monitoring, pest control

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Abstract
The AED 2000 and 2010 are extremely sensitive listening devices which can effectively detect and monitor termite activity through a wave guide (e.g. bolt) both qualitatively and quantitatively. Experiments conducted with one to ten thousand termites from differing colonies infesting wood in buckets demonstrated that acoustical emission detector readings significantly increased when number of termites increased. Termites were also detected in infested trees with the installation of several wave guides into their trunks. These devices can detect termites and changes in termite activity caused by changes in termite numbers, making it an effective pest management professional and research tool for finding and evaluating termite infestations and efficacy of treatments in specific locations.

Introduction

Total economic loss due to termites in the United States has been estimated at $11 billion per year, and where they occur, the Formosan termite, *Coptotermes formosanus* Shiraki (FST), is the most devastating termite pest in the world (Su, 2002). The FST was introduced into the United States from Asia when troops and equipment returned from World War II (Su & Tamashiro, 1987). In addition to structural infestations, *C. formosanus* infestations of living trees are common (Osbrink et al., 1999; Osbrink & Lax, 2002; Ring et al., 2002; Osbrink & Lax, 2003).

Development of techniques for detecting hidden termite infestations have produced only a few successful alternatives to traditional visual inspection methods (Lewis, 1997). Efficient non-invasive detection of termite activity can provide timely location of an infestation thereby reducing economic impact. Non-invasive detection is also ideal for evaluating the efficacy of control efforts because non-invasive monitoring has no effect on population dynamics. Conversely, invasive monitoring techniques can drive termites away from the monitor, creating an artifact of apparent control because of relocation of the termites (Aluko & Husseneder, 2007). Alternatives to visual inspection include monitoring devices with sensors that detect acoustic emissions of termites in wood (Fujii et al., 1990; Lewis & Lemaster, 1991; Noguchi et al., 1991; Robbins et al., 1991). Acoustic emission sensors are successful because they are nondestructive and operate at high frequencies (ca. 40 kHz) where there is negligible background noise to interfere with detection and interpretation of insect sounds (Lewis & Lemaster, 1991; Robbins et al., 1991). Acoustic emission systems have been applied as research tools to estimate termite population levels (Fujii et al., 1990, Lewis & Lemaster, 1991; Scheffrahn et al., 1993; Osbrink et al., 2011). Acoustic emission systems are also ideal for detection of termites in trees (Osbrink et al., 1999; Kramer, 2001; Mankin et al., 2002; Osbrink et al., 2011).

Understanding the efficacy and dynamics of acoustical detection is critical to it being successfully integrated

Open access journal: http://periodicos.uefs.br/ojs/index.php/sociobiology
ISSN: 0361-6525

into an effective pest management strategy. The central objective of this research was to determine the efficacy of using the AED 2000 acoustical emissions detector (Acoustical Emissions Consulting, Inc Fair Oaks, CA) to detect and quantify termite infestations. To meet this objective, studies were conducted to monitor *C. formosanus* through acoustical emission detection both in the laboratory and in trees outdoors. These studies provide evidence that AED significant potential for application in termite management efforts.

Materials and Methods

Acoustical Emission Detector (AED)

An AED 2000 acoustical emissions detector (Acoustical Emissions Consulting, Inc Fair Oaks, CA) was used to quantify termite activity. Lag bolt wave guides (76.2 or 150 x 9 mm) were screwed horizontally into pre-drilled pilot holes in wood substrates. Acoustical emissions were detected with a sensor probe (Model SP-1L with Model DMH-30 high force magnetic accessory attachment, Acoustic Emission Consulting, Inc). AED counts were acquired for 60 s with accompanying software, which converts termite sounds to counts per second and enters them into Excel (Microsoft, Redmond WA). Only the numbers of counts in the first 10 s of the 60 s recording were used to represent each unique individual recording. If the first 10 s of recording was contaminated with interference noise (elevated spiked counts), the first 10 s of recording following the cessation of interference noise were used to represent the unique individual recording. Comparisons also were made between the AED 2000 and the more recently manufactured AED 2010 (Acoustical Emissions Consulting, Inc Fair Oaks, CA).

Laboratory Bucket Tests

A vertically oriented section of spruce (Picea sp.) 38 x 89 mm (2x4 inch) dimensional lumber 17 cm in length was attached to the inner side of a lidded plastic buckets (3.79 l, 18.5 cm height x 20 cm diam.) with 2 horizontally applied drywall screws (high and low) and central lag bolt wave guide (76.2 x 9 mm). The head of the lag bolt was accessible from the outside of the lidded bucket (Fig. 1). The bucket was filled to within 4 cm of top with a moist (≈ 20% water wt/wt) mixture of sand and vermiculite (50:50 by volume). Ten holes were created in the sand-vermiculite substrate with a 5 ml pipette to increase surface area and accelerate acclimatization of termites. Four buckets were prepared for each of 4 termite densities (0, 1,000, 5,000, and 10,000 termites per bucket), in which each density level represents 4 distinct colonies (A, B, C, and D), one colony per bucket. In laboratory bucket tests there were 4 replicates (bucket A, B, C, D), each replicate consisting of a 10 s recording from a specific bucket. Termites were obtained from bucket trap monitors (Su & Scheffrahn, 1986) and termite numbers determined by weight. Soldier proportions were about 10%, unchanged from when collected.

Termite Density Response at 7 and 14 d.

Formosan termites were placed in buckets on day 0 (0 d) as described above. Buckets were held in the laboratory (≈ 26.7º C). On 7 d and 14 d AED readings were taken from each bucket. In laboratory bucket tests there were 4 replicates (bucket A, B, C, D), each replicate consisting of a 10 s recording from a specific bucket.

Termite Density Response at Three Temperatures

After completion of readings at 14 d for dose response at 1 temperature, buckets were placed in 3 incubators stabilized at 15, 20, and 25º C, respectively, and evaluated according to the schedule indicated in Table 1. After readings, buckets were rotated to a new temperature (incubator) and allowed 24 h to acclimate before acoustic readings were again taken. Incubators space limitations required the D samples to be split to fit the 12 buckets into three incubators. In laboratory bucket tests there were 4 replicates (bucket A, B, C, D), each replicate consisting of a 10 s recording from a specific bucket.

Disturbance Test

AED recordings were taken before and after the application of three sharp strikes with a screwdriver to the high density laboratory buckets. In laboratory bucket tests there were 4 replicates (bucket A, B, C, D), each replicate consisting of a 10 s recording from a specific bucket.

Field Test on Trees

Nine wave guides in the form of lag bolts (150 x 9 mm) were screwed horizontally into pre-drilled pilot holes in the trunk of test trees facing north, east, south, and west (Fig 1). Four wave guides were installed at ground level, four at 20 cm above ground level, and one into the east side of the trunk at a height of approximately 122 cm from the ground. Test trees consisted of four southern live oak trees (*Quercus virginiana* Philip Miller) with a diameter at breast height (dbh) of ≈ 90 cm, adjacent to Su-bucket-trap-monitors active with *C. formosanus* (Su & Scheffrahn 1986) located on the City Park campus of the Southern Regional Research Center, New Orleans, LA. In field tests on trees, only the numbers of counts in the first 10 s of the 60 s recording were used to represent each unique individual recording. If the first 10 s of recording was contaminated with interference noise (elevated spiked counts), the first 10 s of recording following the cessation of interference noise were used to represent the unique individual recording. In field tests on trees, ten consecutive counts (10 s) were used to calculate mean (± SE) counts per second to quantify termite activity associated with each unique AED tree bolt attachment.

Comparison of AED 2000 with AED 2010.

Eight different recordings from trees were conducted with each model of acoustical emissions detector and results were compared between the AED 2000 and the AED 2010. In field tests on trees, only the numbers of counts in the first 10 s of the 60 s recording were used to represent each unique individual recording. If the first 10 s of recording was contaminated with interference noise (elevated spiked counts), the first 10 s of recording following the cessation of interference noise were used to represent the unique individual recording. In field tests on trees, ten consecutive counts (10 s) were used to calculate mean (± SE) counts per second to quantify termite activity associated with each unique AED tree bolt attachment.

Data Analysis.

Ten consecutive count values (10 s) were used to represent termite activity associated with each unique AED attachment. In laboratory bucket tests there were 4 replicates (bucket A, B, C, D), each replicate consisting of a 10 s recording from a specific bucket. In field tests on trees, ten consecutive counts (10 s) were used to calculate mean (± SE) counts per second to quantify termite activity associated with each unique AED tree bolt attachment. Acoustical data were analyzed using one way analysis of variance (ANOVA) with means separated using the protected Tukey test, $P < 0.05$ (Systat, 2008).

Results

Termite Density Response at 7 and 14 d.

Buckets with no termites produced AED readings of zero (control). There were highly significant differences in termite activity between termite colonies, and acoustical emission activity increased concomitantly with increased termite density (Table 2). The highest density always had significantly greater activity than the lowest. Overall, there was no consistent change in termite acuity between 7 d and 14 d, however at the lowest density there was non-significant but numerically consistent increase in activity (Table 2).

Termite Density Response at Three Temperatures.

Buckets with no termites produced AED readings of zero (control). At low termite density, there was no significant difference in inter-colony activity at all 3 temp (Table 3), but there was a significant increase in termite activity at the highest density with two colonies and combined colonies (Table 4). At 20 and 25º C there was always a significant activity dose response except with colony D which did not statistically but did numerically separate 5k from 10k (Table 3). Combined colonies demonstrated highly significant density dose response at all temps. At the highest density there was always significantly less termite activity at the lowest temp (Table 4). At lower density this temperature separation was not as clearly defined.

Table 1. Incubator temperature and rotation of termite densities.

		Temp (º C)			
Colony	# Termites	10	15	20	25
A	0 1000 5000 10000	Day1	Day 2	Day 3	
B	0 1000 5000 10000	Day 3	Day 1	Day 2	
C	0 1000 5000 10000	Day 2	Day 3	Day 1	
D	0 1000	Day 1	Day 2	Day 3	
D	5000 10000	Day 3	Day1	Day 2	

Disturbance Test

Three of the four colonies displayed a significant decrease in termite activity, and one colony had a numerical but non-significant increase in recorded activity (Table 5). Qualitatively, termite activity could be heard though the earphones to increase for a brief time before the recording began.

Field Test on Trees

Out of the nine bolts per tree, generally only one or two had significantly high termite activity, with the remainder of the bolts displaying low termite activity (Table 6).

Comparison of AED 2000 with AED 2010

Of eight different recordings of trees, there was little difference observed between the AED 2000 and AED 2010. The AED 2010 had consistently higher readings that may indicate that it may be slightly more sensitive (Table 7).

Discussion

Termite Density Response at 7 and 14 d.

Having highly significant differences in termite activity between colonies is consistent with the generally accepted understanding that there can be profound inter-colony differences. These findings support the suggestion of Su and La Fage (1984) to use multiple colonies when conducting bioassays. A possible explanation of the non-significant but numerically consistent increase in activity at the lowest density is that it takes longer for fewer termites to create a gallery system in the wood. Increased size of galleries increases the surface area occupied by termites creating an opportunity for increased generation of acoustical emission.

Termite Density Response at Three Temperatures.

Dose responses to density and temperature were demonstrated most clearly with the combined colony data due to the increased number of samples. These results demonstrate the efficacy of using an acoustical emission detector to detect and monitor termite activity. Because there were significant differences in the AED readings based on termite density, the detector can be useful not only in detecting the presence of termites but also in estimating population density in infested trees or structures.

Disturbance Test.

Though a post-disturbance decrease in activity occurred, a substantial amount of termite activity remained (Table 5). Qualitatively, earphone monitoring indicated an immediate, brief increase in termite sounds in all instances that is consistent with absconding. Unpublished video has shown FST to cease feeding and abscond following a disturbance, and soldiers (incapable of chewing wood) produce characteristic termite sounds monitored with the AED 2000 (WO personal observation). Additionally, the presence of red imported fire ant colonies, Solenopsis invicta Buren, at tree study sites have produced sounds similar to termites (WO personal observation). Thus, results indicate that AED 2000 recordings are created by termite movement and not feeding activity, possibly a result tarsal claw-substrate interaction. This is inconsistent with reports of Scheffrahn et al. (1993) and Fujii et al. (1990) who attribute signals detected by their devices specifically to termite feeding. This difference in interpretation of results may reflect differences in the nature of the disturbance or in the specifics of the detection mechanism.

Field Test on Trees.

Of the nine bolts per tree, generally only one or two transmitted high termite activity while the remainder of the bolts displayed low termite activity (Table 6). Energy attenuates much more rapidly horizontally across the trunk than vertically up and down the trunk (Mankin et al., 2002), suggesting that termite activity is oriented vertical to the bolt. Thus, a single bolt, or readings from a single point cannot determine that a tree is not infested with termites.

Limitations of AED 2000 and AED 2010.

Certain events can interfere with successful recording of termite activity including wind noise, trucks with squeaking breaks, generators, crowd noise, etc. Wind speeds > 14 km/h interfere with recording activity in trees because of leaf flutter, and Excel recordings do not distinguish termite events from unrelated sound events, therefore maintaining a log with qualitative notes is advised. Elevated wind can be a common cause for cancellation of field tests, and demands flexibility in scheduling. Radio interference can also become an issue that may be mitigated by incorporating ferrite chokes and the shortest cord possible.

In conclusion, the AED 2000 and 2010 are extremely sensitive devises which can detect termite activity channeled through a wave guide. Because of the significant increases in AED readings with increasing group size, a trained pest management professional would be able to use the acoustical detectors to estimate the severity of an infestation, in addition to merely determining the presence or absence of termites. Use of this technology may be quite valuable in specific applications such as pre- and post-treatment evaluations of termite activity. In applications where multiple locations are to be evaluated, interference from external noise can become an issue.

Acknowledgements

We thank R. Davey, K. Lohmeyer, J.M. Pound, and S. Skoda for agreeing to review this manuscript and valuable improvements contributed by their reviews.

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Figure 1. AED 2000 attached to bucket and tree.

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Table 2. Acoustical emission dose response (mean ± SE) by termites (10 s).

	Number termites (x1,000)					
	7 d			14 d		
Colony	1	5	10	1	5	10
A	23.8 ± 4.4cB	189.9 ±25.5 aA	235.6 ± 12.3aB	65.8 ± 1.3cA	105.0 ± 8.9bC	129.5 ± 12.4bB
				F = 34.703	df = 5, 59	*P* < 0.001
B	13.3 ± 2.7cBC	96.0 ± 11.9bB	146.8 ± 29.9bC	24.0 ± 3.0cB	152.7 ± 14.2abA	210.8 ± 14.7aC
				F = 26.757	df = 5, 59	*P* < 0.001
C	6.5 ± 1.9dC	39.1 ± 7.4cdB	124.0 ± 16.2bC	19.7 ± 2.6dB	56.9 ± 7.3cB	176.0 ± 16.4aBC
				F = 40.423	df = 5, 59	*P* < 0.001
D	46.4 ± 4.1dA	166.0 ± 9.5cA	744.3 ± 23.4aA	60.7 ± 6.7dA	149.7 ± 16.0cAC	320.2 ± 29.1bA
				F = 229.179	df = 5, 59	*P* < 0.001
	F=25.790 df=3.39 P<0.001	F=20.158 df=3.39 P<0.001	F=195.680 df=3.39 P<0.001	F=36.223 df=3.39 P<0.001	F=13.753 df=3.39 P<0.001	F=17.787 df=3.39 P<0.001

Means within a row (lower case) or column (upper case.) with same letter are not significantly different, protected Tukey Test (P > 0.05).

Table 3. Varied temperature with AED dose response (mean ± SE) by termites (10 s) .

		Colony							
Temp. (º C)	# Termites (x1,000)	A	B	C	D	Combined			
15	1000	1.5 ± 0.5aB	3.2 ± 0.7aB	2.9 ± 0.8aB	2.9 ± 0.9aB	2.6 ± 0.4aC	*F* = 0.808	df = 4, 79	*P* = 0.524
	5000	17.4 ± 2.8abAC	28.0 ± 4.6aAC	2.7 ± 0.6cB	10.4 ± 2.7bcB	14.6 ± 2.1bB	*F* = 6.463	df = 4, 79	*P* < 0.001
	10000	15.5 ± 3.4bC	18.4 ± 2.3bC	34.3 ± 6.0abA	57.3 ± 6.0aA	31.3 ± 3.5bA	*F* = 7.678	df = 4, 79	*P* < 0.001
		F = 11.7	*F* = 17.418	*F* = 26.681	*F* = 59.908	*F* = 37.647			
		df = 2, 29	df = 2, 29	df = 2, 29	df = 2, 29	df = 2, 119			
		P < 0.001	*P* < 0.001	*P* < 0.001	*P* < 0.001	*P* < 0.001			
20	1000	3.0 ± 1.2aC	2.1 ± 0.7aC	1.1 ± 0.4aC	2.2 ± 0.4aB	2.1 ± 0.4aC	*F* = 0.767	df = 4, 79	*P* = 0.550
	5000	25.2 ± 6.1abB	28.1 ± 5.1abB	23.9 ± 4.1bB	51.1 ± 9.4aA	32.1 ± 3.6abB	*F* = 2.623	df = 4, 79	*P* = 0.041
	10000	45.3 ± 5.4aA	57.8 ± 6.2aA	54.1 ± 4.9aA	63.9 ± 7.6aA	55.3 ± 3.1aA	*F* = 1.204	df = 4, 79	*P* = 0.316
		F = 19.643	*F* = 36.039	*F* = 57.422	*F* = 21.872	*F* = 93.620			
		df=2.29	df=2.29	df=2.29	df=2.29	df=2.29			
		P < 0.001	*P* < 0.001	*P* < 0.001	*P* < 0.001	*P* < 0.001			
25	1000	17.0 ± 5.2aC	2.4 ± 0.6aC	14.1 ± 3.9aC	5.8 ± 1.7aC	13.5 ± 2.2aC	*F* = 2.751	df = 4, 79	*P* = 0.034
	5000	53.4 ± 4.6aB	42.7 ± 5.6abB	30.9 ± 4.3bB	32.3 ± 4.5bB	42.5 ± 2.8abB	*F* = 3.195	df = 4, 79	*P* = 0.018
	10000	159.3 ± 12.9aA	65.9 ± 6.2bcA	69.7 ± 4.9bcA	46.3 ± 3.3cA	108.7 ± 9.4bA	*F* = 10.226	df = 4, 79	*P* < 0.001
		F = 76.815	*F* = 44.548	*F* = 42.584	*F* = 37.628	*F* = 70.673			
		df = 2, 29	df = 2, 29	df = 2, 29	df = 2, 29	df = 2, 29			
		P < 0.001	*P* < 0.001	*P* < 0.001	*P* < 0.001	*P* < 0.001			

Means within a row (lower case) or column (upper case) with same letter are not significantly different, protected Tukey Test (P > 0.05).

Table 4. Temperature and termite density; mean (± SE) number of AED counts (10 s).

Temp. (º C)	Number termites (x1,000)	Colony A	B	C	D	Combined
15	10	15.5 ± 3.3c	18.4 ± 2.3b	34.3 ± 6.0b	57.3 ± 6.0a	31.4 ± 3.5c
20	10	45.3 ± 5.4b	57.8 ± 6.2a	57.8 ± 5.1a	63.9 ± 7.6a	55.3 ± 3.1b
25	10	159.3 ± 12.9a	65.9 ± 6.2a	69.7 ± 4.9a	46.3 ± 3.3a	108.7 ± 9.4a
		$F = 83.805$	$F = 23.678$	$F = 26.681$	$F = 2.290$	$F = 42.547$
		df = 2, 29	df = 2, 29	df = 2, 29	df = 2, 29	df = 2, 119
		$P < 0.001$	$P < 0.001$	$P < 0.001$	$P = 0.121$	$P < 0.001$
15	5	17.4 ± 2.8a	28.0 ± 4.6a	2.7 ± 0.6b	10.4 ± 2.7b	14.6 ± 2.1c
20	5	3.0 ± 1.2b	28.1 ± 5.1a	23.9 ± 4.1a	51.1 ± 9.4a	32.1± 3.6b
25	5	17.0 ± 5.2a	42.7 ± 5.6a	30.9 ± 4.3a	32.3 ± 4.5a	42.5 ± 2.8a
		$F = 5.566$	$F = 2.754$	$F = 18.182$	$F = 10.796$	$F = 23.928$
		df = 2, 29	df = 2, 29	df = 2, 29	df = 2, 29	df = 2, 119
		$P = 0.009$	$P = 0.082$	$P < 0.001$	$P < 0.001$	$P < 0.001$
15	1	1.5 ± 0.5b	3.2 ± 0.7a	2.9 ± 0.9b	2.9 ± 0.9a	2.6 ± 0.4b
20	1	3.0 ± 1.2b	2.1 ± 0.7a	1.1 ± 0.4b	2.2 ± 0.4a	2.1 ± 0.4b
25	1	17.0 ± 5.2a	2.4 ± 0.6a	14.1 ± 3.9a	5.8 ± 1.7a	13.5 ± 2.2a
		$F = 7.659$	$F = 0.699$	$F = 9.171$	$F = 2.859$	$F = 24.819$
		df = 2, 29	df = 2, 29	df = 2, 29	df = 2, 29	df = 2, 119
		$P = 0.002$	$P = 0.506$	$P < 0.001$	$P = 0.075$	$P < 0.001$

Means within a row with same letter not significantly different, protected Tukey Test (P > 0.05).

Table 5. Pre - and post - disturbance mean (± SE) number AED counts (10 s) of termites.

Colony	Termite disturbance Pre-	Post-			
A	126.0 ± 9.5a	222.8 ± 109.5a	$F = 0.776$	df = 1, 19	$P = 0.390$
B	141.0 ± 8.3a	70.6 ± 10.5b	$F = 27.742$	df = 1, 19	$P < 0.001$
C	255.3 ± 17.4a	180.8 ± 27.9b	$F = 5.137$	df = 1, 19	$P = 0.036$
D	272.5 ± 19.1a	91.4 ± 18.9b	$F = 45.558$	df = 1, 19	$P < 0.001$

Means within a row with same letter not significantly different, protected Tukey Test (P > 0.05).

Table 6. AED counts (10 s) of termites in trees (mean ± SE).

Oak Trees	Wave guide location on tree: North		East			South		West	
	Base	20 cm	Base	20 cm	122 cm	base	20 cm	base	20 cm
1	3.0 ± 0.1c	4.2 ± 0.8c	2.8 ± 0.5c	14.3 ± 4.4bc	2.8 ± 2.8c	23.5 ± 5.7b	2.1±0.4c	3.5±0.9c	58.2±5.2a
							$F = 37.895$	df = 8, 89	$P < 0.001$
2	3.7 ± 0.1b	3.2 ± 0.1b	1.9 ± 0.5b	2.4 ± 0.6b	4.2 ± 0.6b	3.2 ± 0.7b	354.6±55.4a	35.1±6.1b	4.1±1.3b
							$F = 39.070$	df = 8, 89	$P < 0.001$
3	276.0 ± 9.1a	4.3 ± 1.0b	3.9 ± 0.9b	5.0 ± 0.5b	5.0 ± 0.7b	8.9 ± 2.7b	3.2±0.5b	4.3±0.9b	1.2±0.9b
							$F = 777.511$	df = 8, 89	$P < 0.001$
4	25.6 ± 4.1b	0.0 ± 0.0b	3.9 ± 0.6b	149.7 ± 19.1a	5.9 ± 0.8b	3.3 ± 0.9b	6.7±1.2b	0.0±0.0b	4.6±0.8b
							$F = 54.887$	df = 8, 89	$P < 0.001$

Means within a row with same letter not significantly different, protected Tukey Test (P > 0.05).

Table 7. Comparison of AED 2000 with AED 2010 with AED counts (10 s) of termites in trees (mean ± SE).

Oak	Trees	Wave guide location on tree: North	East	South	West
6	AED 2010	2.6 ± 0.9a	8.9 ± 2.0a	17.9 ± 3.3a	3.5 ± 1.5a
	AED 2000	0.3 ± 0.2b	1.9 ± 0.8b	12.7 ± 2.5b	0.9 ± 0.6a
		$F = 6.065$	$F = 10.357$	$F = 1.535$	$F = 2.500$
		df = 1, 19	df = 1, 19	df = 1, 19	df = 1, 19
		$P = 0.024$	$P = 0.005$	$P = 0.231$	$P = 0.131$
				South (March)	South (June)
350	AED 2010	1.9 ± 1.0a	0.5 ± 0.3a	13.7 ± 3.6a	47.2± 6.0a
	AED 2000	0.9 ± 0.4a	0.0 ± 0.0a	8.2 ± 1.3a	27.2 ± 2.3b
		$F = 0.820$	$F = 2.143$	$F = 2.041$	$F = 9.571$
		df = 1, 19	df = 1, 19	df = 1, 19	df = 1, 19
		$P = 0.377$	$P = 0.160$	$P = 0.170$	$P = 0.006$

Means within a row with same letter not significantly different protected, Tukey Test (P > 0.05).